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L. W. Parker

Groundscreen Characterization

MITRE
Bedford, Massachusetts

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ABSTRACT

The screen parameter for a Fresnel reflection coefficient model is calculated for a plane wave obliquely incident on a parallel-wire grid of infinite extent, in proximity to and parallel to flat lossy earth. J. R. Wait has published mathematical models for this problem. The numerical results from a computer code implementing Wait's expansion models allow an assessment of the range of validity for a simplified screen parameter formula. The screen parameter developed in this paper is not applicable to grids of electrically-small extent (small compared to a wavelength) or to grids consisting of disconnected electrically-small panels of grids because diffraction and reflection at the edge of the grids causes the current distribution on the grids to differ appreciably from that on a grid of infinite extent.

ACKNOWLEDGMENT

The author is indebted to M. M. Weiner for many stimulating and useful discussions.

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SECTION 1

GROUNDSCREEN CHARACTERIZATION

The electrical properties of a groundscreen may be characterized by a screen parameter in a Fresnel reflection coefficient model for a plane wave obliquely incident on a parallel-wire grid of infinite extent, near and parallel to a lossy earth. This paper presents numerical results from a MITRE computer program based on theoretical series expansions developed by Wait [1, 2] for the screen parameter. These results are compared with a simplified screen-parameter formula.

SECTION 2

MODEL METHODOLOGY

Figure 1 shows the geometry for the case of parallel polarization (denoted by subscript p in Figure 3) with the plane of incidence parallel to the wires. This is the case treated by Wait in reference 1. The figure defines the free-space wave number k, incident and reflected fields, grid parameters such as height above ground h, wire spacing s and wire radius b, and earth parameters such as complex permittivity $\varepsilon_r - j\,(\sigma/\omega\varepsilon_0)$ and wave number k_e. For thin grid wires, the equivalent circuit may be characterized by a wire-grid impedance Z_g in shunt with a compound transmission line comprised of free space and earth (see figure 2).* The impedance Z_g can be expressed in terms of a dimensionless screen parameter δ (see figure 3). Large impedance implies low reflectivity, and vice versa.

The methodology for determining the screen parameter δ usually follows three main steps:

Step 1 Expand in series, e.g.:

- Hankel series used by Wait [1], [2]
- Waveguide mode series used by Fan [3]
- Floquet/Fourier series used by Otteni [4]
- Fourier series used by Skwirzynski and Thackray [5]

Step 2 Determine series coefficients by matching electric-field tangential components at the wire surfaces so that the net value of this component vanishes; this gives the currents.

Step 3 Calculate screen parameter in terms of series coefficients.

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* It should be noted that when the wire grid is in free space (in the absence of earth), one may set $h = \infty$, or equivalently, set Z_g = intrinsic impedance of free space.

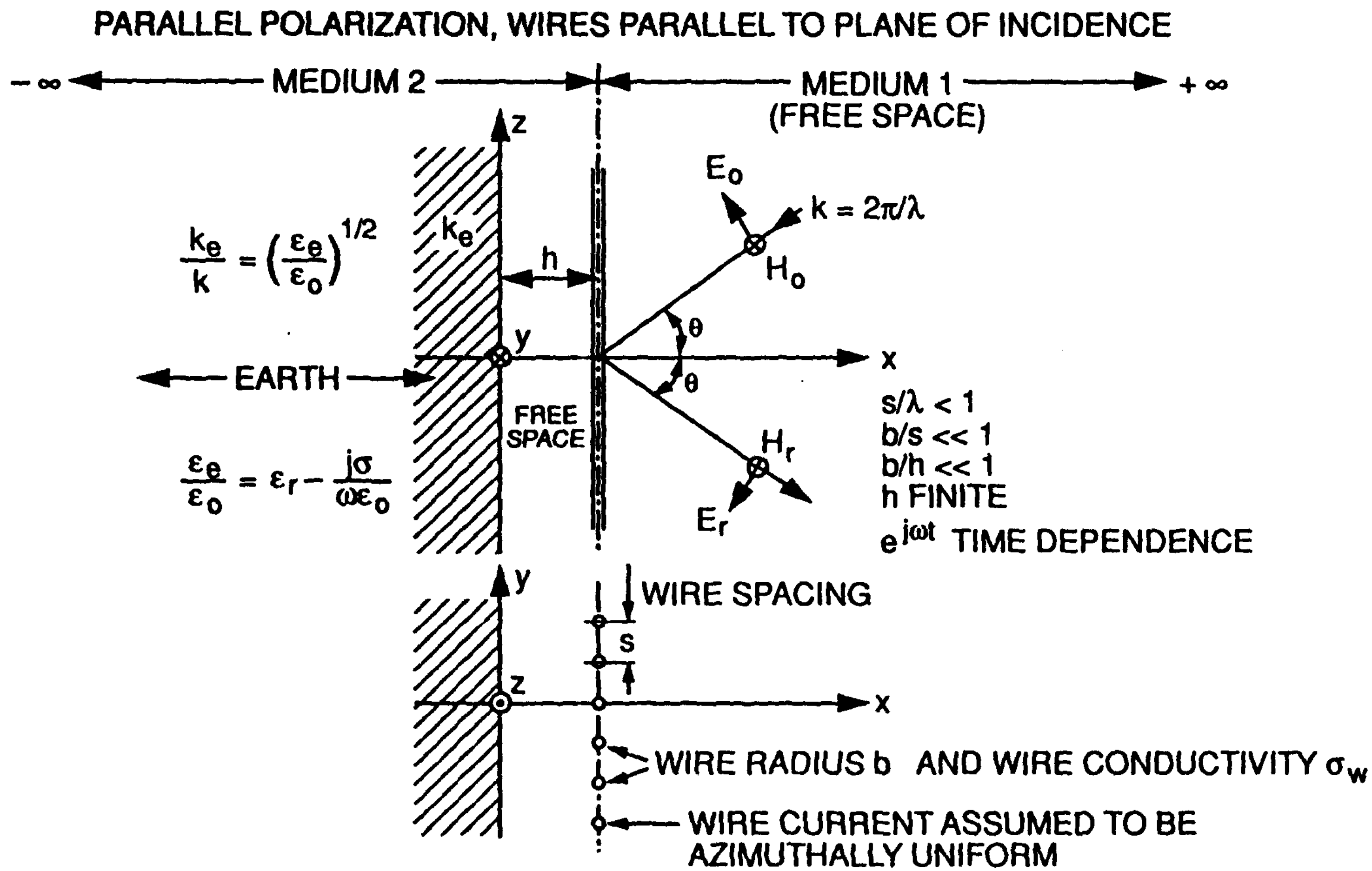

Figure 1. Geometry for Parallel Polarization with Plane of Incidence Parallel to the Wires (Wait, 1962)

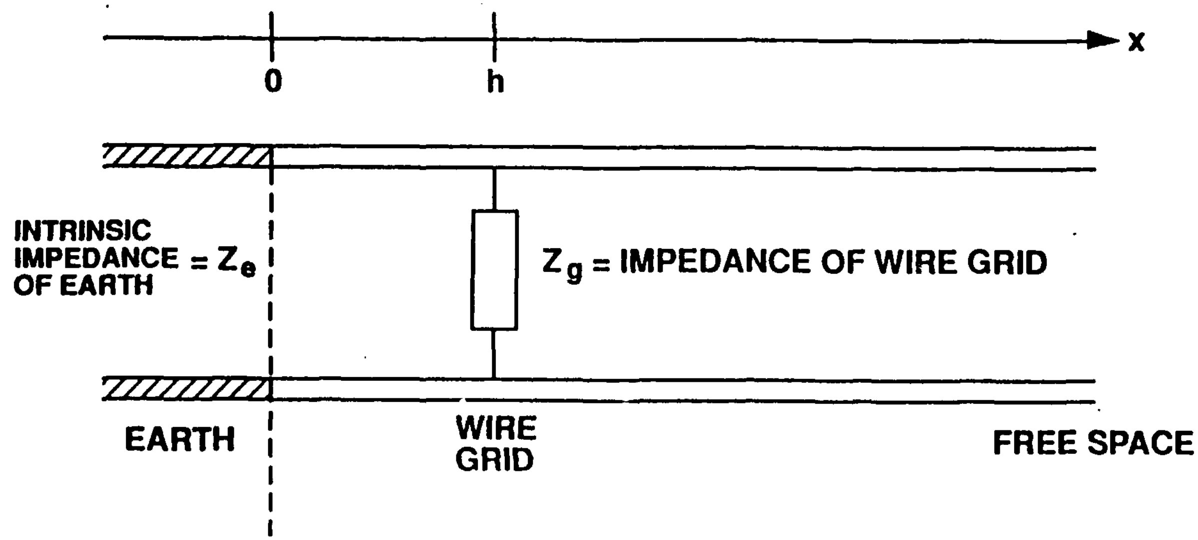

Figure 2. Equivalent Circuit with Grid Impedance Shunting Compound Transmission Line (Wait, 1962)

$R_p(\theta) = E_r/E_o$ = Fresnel reflection coefficient $= \dfrac{\eta_2 \cos\theta_t - \eta_o \cos\theta}{\eta_2 \cos\theta_t + \eta_o \cos\theta}$

$T_p(\theta)$ = Fresnel transmission coefficient $= 1 + R_p(\theta)$

η_2 = Effective impedance of medium 2 (wire grid in shunt with earth)
$= Z_g Z_e / (Z_g + Z_e)$

η_o = Intrinsic impedance of free space $= (\mu_o/\varepsilon_o)^{1/2}$

θ_t = Complex angle of refraction in medium 2
$= \arccos [1 - (\eta_2/\eta_o)^2 \sin^2\theta]^{1/2}$

Z_g = Impedance of wire grid $= j\,\eta_o\,\delta \cos^2\theta$

Z_e = Intrinsic impedance of earth $= (\mu_o/\varepsilon_e)^{1/2}$

δ = Screen parameter $= \delta_o + \Delta'$

δ_o = Simplified-model screen parameter
$= (s/\lambda)\;[\ln\;(s/2\pi b) + (1 + j)\,(f_{MHz}/10\,\sigma_w)^{1/2}\, s/b]$

Δ' = Correction term, which for normal incidence is equal to Wait's correction Δ (Wait, 1962, Eq. 22)

For free space

$$\Delta' = \Delta = \frac{s}{\lambda} \sum_{m=1}^{\infty} \left\{-(1/m) + [m^2 - (s/\lambda)^2 \cos^2\theta]^{-1/2}\right\}$$

On the earth surface and for normal incidence:

$$\Delta' = \Delta = \frac{s}{\lambda} \sum_{m=1}^{\infty} \left\{-(1/m) + 2/\left[\sqrt{m^2 - (s/\lambda)^2} + \sqrt{m^2 - (s/\lambda)^2 (\varepsilon_e/\varepsilon_o)}\right]\right\}$$

Figure 3. Definitions, Wait's 1962 Model

The essence of Wait's model for the screen parameter δ is contained in figure 3, which shows Wait's expansion for the screen parameter δ, for the case of normal incidence. The exact screen parameter can be decomposed into the simplified model δ_0, plus an additive correction Δ, where Δ is expressed as an infinite series.

The full Wait expansion for the general problem is as follows:

$$\delta = (s/\lambda)C^2\,\{\ell n(s/2\pi b) - R_o\,\ell n[1-\exp(-4\pi\,h/s - 2\pi b/s)] + \Delta\} + sZ_i$$

where Δ is a summation to be defined below, and where Z_i denotes the internal impedance of the grid wires. R_0 is defined (in our notation) as:

$$R_o = \frac{(1+A^2)(1-B^2)+\sin^2\theta(1-A^2)^2}{(1+A^2)(1+B^2)-\sin^2\theta(1-A^2)^2}$$

where:

$$A^2 = (k/k_e)^2\,(\cos\theta/\cos\theta_t)^2$$

$$B^2 = (\cos\theta/\cos\theta_t)^2$$

$$C^2 = \cos^2\theta$$

$$C_2^2 = [1-(k/k_e)^2\sin^2\theta]$$

We will also need to define (for integer m):

$$R_m = \frac{\left(M+M_2A^2\right)\left(M-M_2B^2\right)+m^2\sin^2\theta(1-A^2)^2}{\left(M+M_2A^2\right)\left(M+M_2B^2\right)-m^2\sin^2\theta(1-A^2)^2}$$

where

$$M^2 = m^2 - (s/\lambda)^2\, C^2$$

$$M_2^2 = m^2 - (s/\lambda)^2\, (k_e/k)^2\, C_2^2$$

Then the term Δ may be expressed as the infinite sum:

$$\Delta = \sum_{m=1}^{\infty} \Delta_m$$

where

$$\Delta_m = \frac{1}{M}\left[1 + R_m \exp(-4\pi M h/s)\right] - \frac{1}{m}\left[1 + R_o \exp(-4\pi m h/s)\right]$$

SECTION 3

COMPUTATIONAL RESULTS

Figure 4 shows the variation of grid impedance modulus, with the angle of incidence and the height of the grid above ground. This variation contrasts with the constancy predicted by the simplified screen-parameter model. Figure 4 agrees with a similar figure published by Wait [1], thus verifying the correctness of the computer program. The simplified model is seen to be valid for normal incidence. The apparent constancy of the grid impedance for negative h (depth below the earth surface) is valid only for shallow depths. At sufficiently large depths, the attenuation is so great that the grid can have no effect. Therefore its impedance would tend to become infinite with increasing depth. The assumed parameters are shown in figure 4. (Wait's wire conductivity is finite but large enough to be essentially infinite.)

Figures 5 and 6 present new results showing how the screen parameter (simplified versus exact model) varies with wire spacing, at zero-degrees and 90-degrees incidence angle, respectively, for a height of one meter above ground and the same fixed parameters as in figure 4. The impedance rises (reflectivity falls off) with increasing spacing. The simplified model (solid curve "without correction") agrees with the exact model (dashed curve "with correction") at small spacings, at zero degrees (normal) incidence. The simplified model overestimates impedance at the larger spacings. At 90-degrees (grazing) incidence and small spacings, the exact impedance falls well below that of the simplified model. These results are consistent with figure 4.

Other new results as a function of the ratio of wire radius to wire spacing are presented in figures 7 and 8, for free space and for normal and 60-degree incidence, respectively. Four wire thicknesses are represented by the curves in figures 7 and 8. Some trends, such as variation with spacing, are similar to those indicated in the previous figures. The impedance decreases (reflectivity increases) as wire thickness increases.

At normal incidence, the simplified screen-parameter model is correct for small spacings. The deviations that occur at larger spacings do not appear to be significant.

At 60-degrees incidence (figure 8), the exact impedance is significantly below the simplified-model impedance, at all spacings and wire thicknesses.

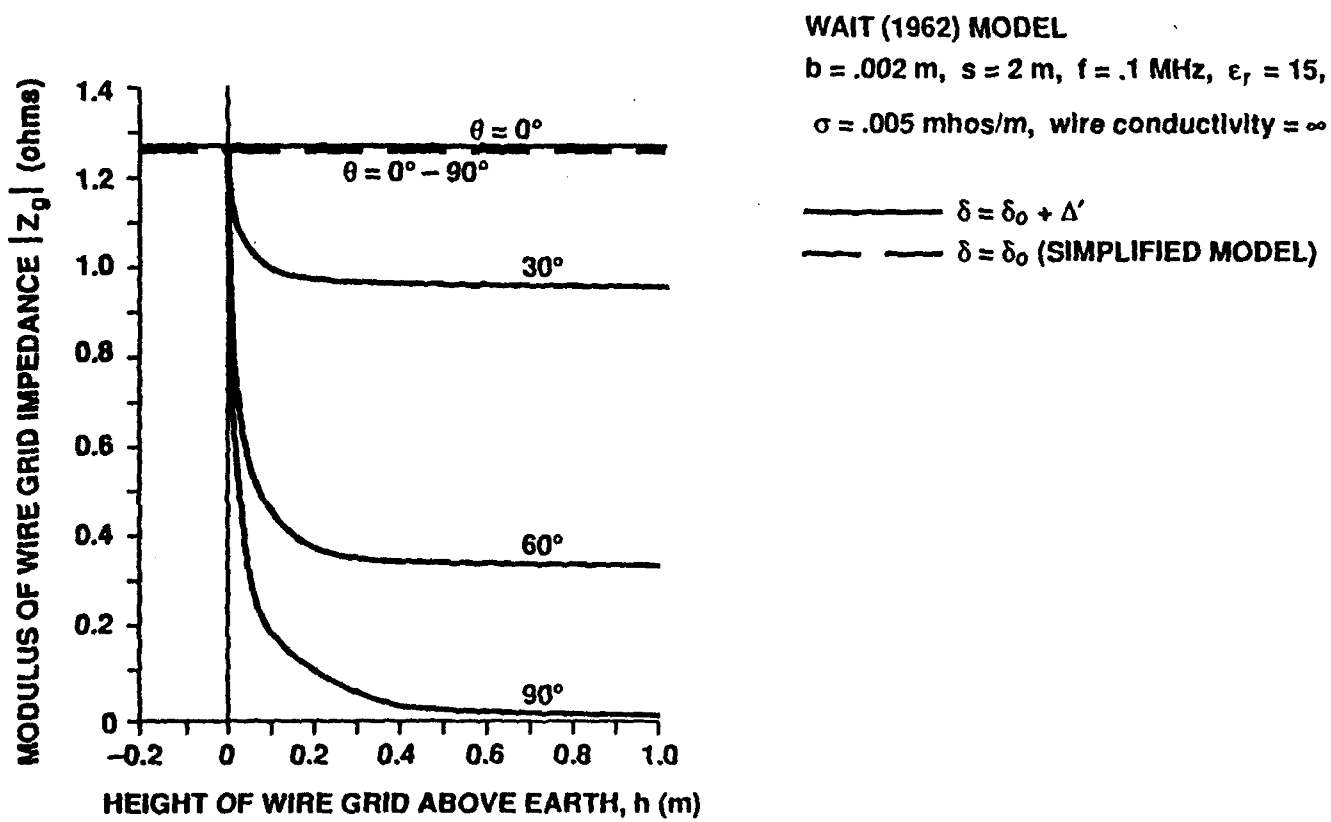

Figure 4. Wire Grid Impedance versus Height Above Ground at Various Angles of Incidence (Wait's Parameters)

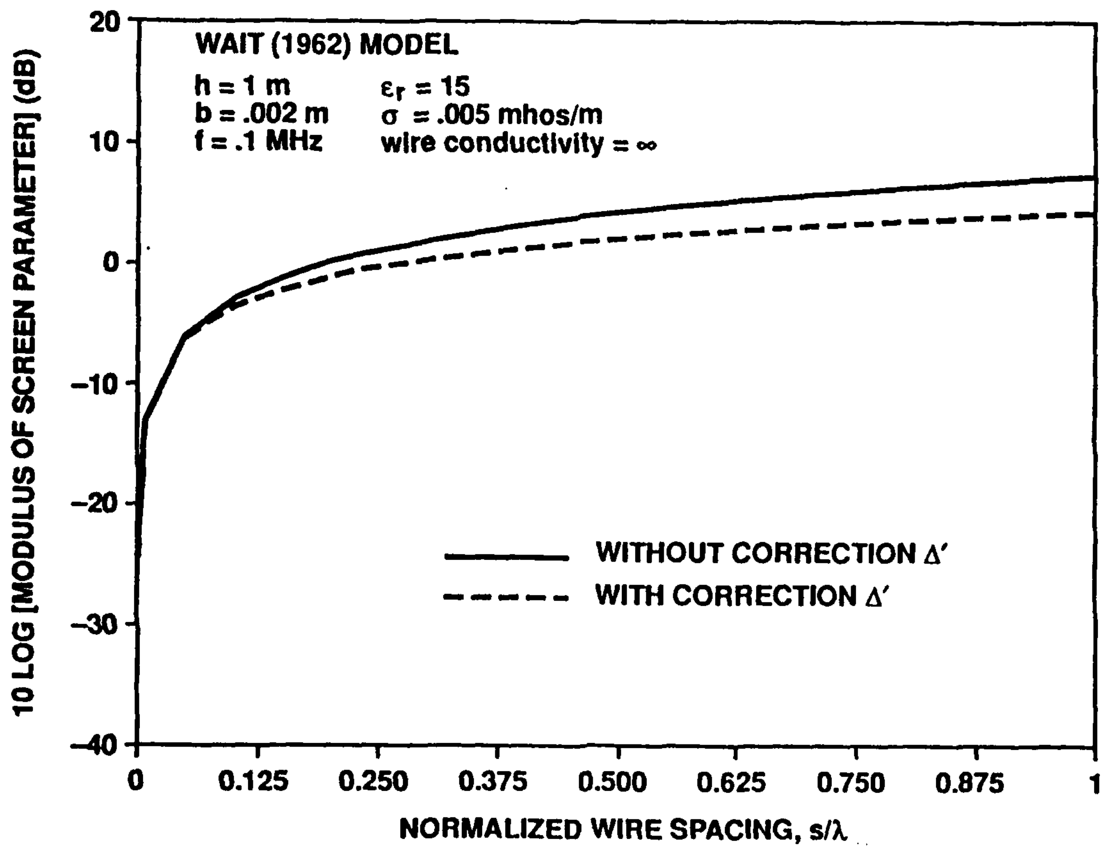

Figure 5. Screen Parameter, $\theta = 0^{\circ}$

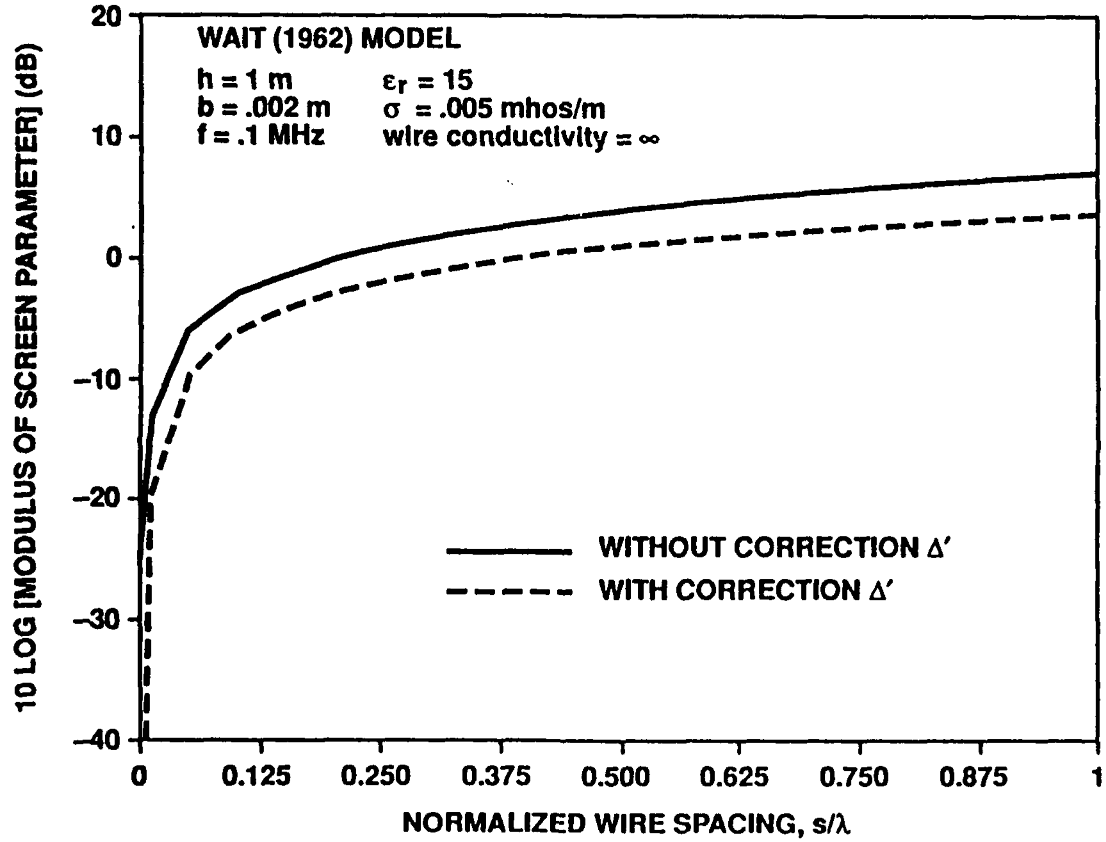

Figure 6. Screen Parameter, $\theta = 90^\circ$

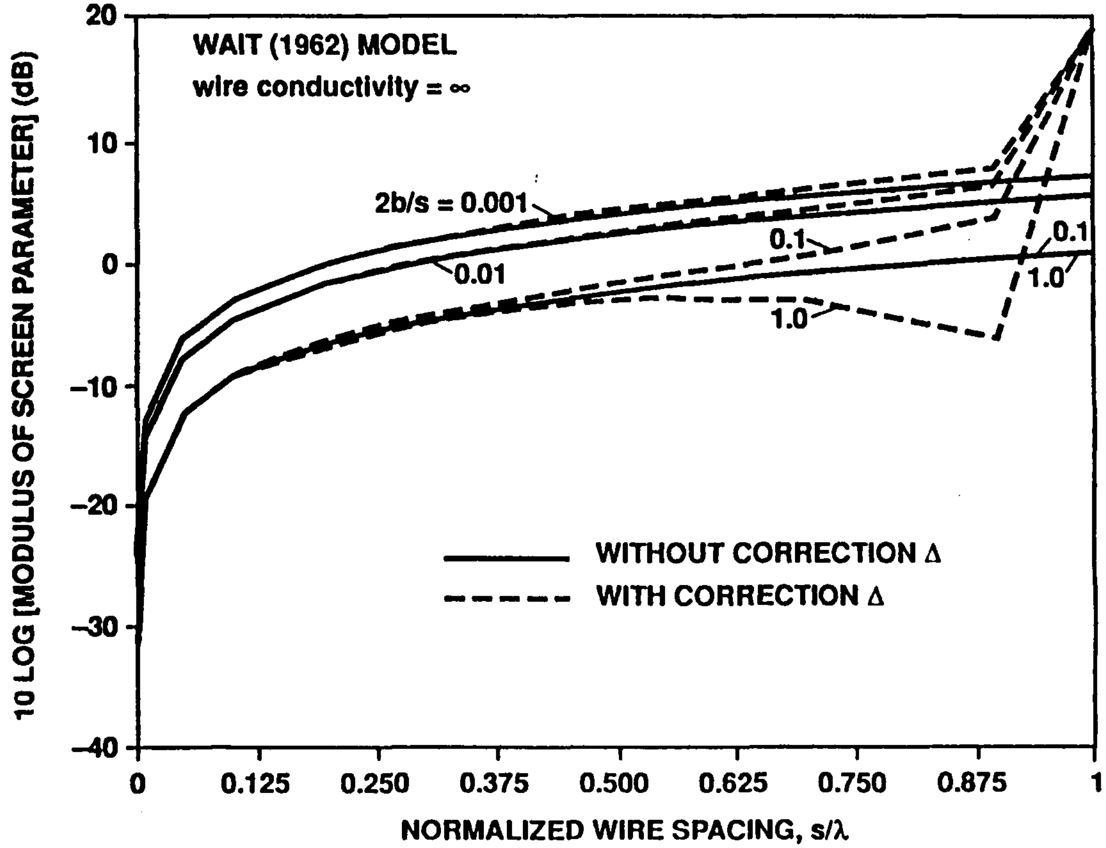

Figure 7. Free-Space Screen Parameter, θ = 0°

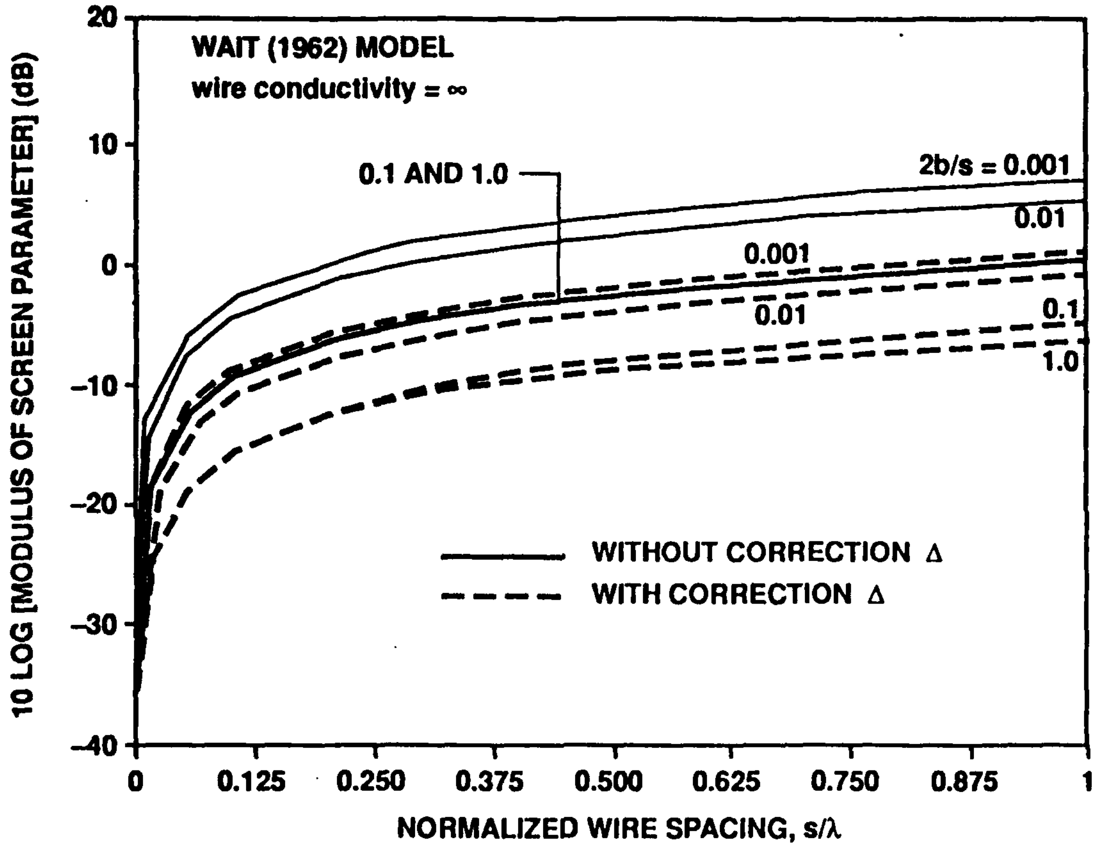

Figure 8. Free-Space Screen Parameter, $\theta = 60°$

SECTION 4

CONCLUSIONS

Based on the computational results shown above, the simplified screen-parameter formula (see figure 3) is valid ($\delta = \delta_0$) when

(a) The grid is on (or slightly below) the earth surface, regardless of the angle of incidence, and the wire spacing is less than a wavelength,

or,

(b) The grid is in free space, the incidence is normal, and the wire spacing is small compared with the wavelength.

In both cases the wire radius is assumed to be much smaller than the spacing.

LIST OF REFERENCES

1. Wait, J. R., September 1962, "Effective Impedance of a Wire Grid Parallel to the Earth's Surface," *IRE Trans. Antenna and Propagation*, Vol. AP-10, No. 5, pp. 538-542.

2. Wait, J. R., April 1957, "The Impedance of a Wire Grid Parallel to a Dielectric Interface," *IRE Trans. Microwave Theory and Techniques*, Vol. MTT-5, pp. 99-102.

3. Fan, D., January 1989, "A New Approach to Diffraction Analysis of Conductor Grids," *IEEE Trans. Antenna and Propagation*, Vol. 37, no. 1, pp. 84-89.

4. Otteni, G. A., November 1973, "Plane Wave Reflection from a Rectangular-Mesh Ground Screen," *IEEE Trans. Antenna and Propagation*, Vol. AP-21, no. 6, pp. 843-851.

5. Skwirzynski, J. K., and J. C. Thackray, 1959, "Transmission of Electromagnetic Waves Through Wire Gratings (Theory)," *Marconi Review*, 2nd Quarter, Vol. 22, pp. 77-90.

BIBLIOGRAPHY

Astrakhan, M. I., 1968, "Reflection and Screening Properties of Plane Wire Grids," *Radio Eng.* (Moscow), vol. 23, pp. 76-83.

Born, M., and E. Wolf, 1965, *Principles of Optics*, Pergamon, Oxford, pp. 564-565.

Elliott, R. S., 1981, *Antenna Theory and Design*, Prentice-Hall, Englewood Cliffs, NJ, pp. 323-325.

Fan, D., January 1989, "A New Approach to Diffraction Analysis of Conductor Grids, Part I - Parallel-Polarized Incident Plane Waves," *IEEE Trans. Antenna and Propagation*, vol. 37, no. 1, pp. 84-89.

Harrington, R. F., 1962, *Time-Harmonic Electromagnetic Fields*, McGraw-Hill, pp. 54-61.

Hill, D. A., and J. R. Wait, January 1973, "Calculated Pattern of a Vertical Antenna with a Finite Radial-Wire Ground System," *Radio Sci.*, vol. 8, no. 1, pp. 81-85.

Hill, D. A., and J. R. Wait, September-October 1978, "Surface Wave Propagation on a Rectangular Bonded Wire Mesh Located Over the Ground," *Radio Sci.*, Vol. 13, no. 5, pp. 793-799.

Kontorovich, M. I., 1963, "Averaged Boundary Conditions at the Surface of a Grating with Square Mesh, *Radio Eng. Electron Phys.*, (USSR), vol. 8, no. 9, pp. 1446-1454.

Kontorovich, M. I., V. Yu Petrun'kin, N. A. Yesepkina and M. I. Astrakhan, 1962, "The Coefficient of Reflection of a Plane Electromagnetic Wave from a Plane Wire Mesh," *Radio Eng. Electron Phys.*, (USSR), vol. 7, no 2, pp. 222-231.

Larsen, T., May 1962, "A Survey of the Theory of Wire Grids," *IRE Trans. Microwave Theory and Techniques*, vol. MTT-10, pp. 191-201.

Larsen, T., January-February 1962, "Numerical Investigation of the Equivalent Impedance of a Wire Grid Parallel to the Interface Between Two Media," *J. Res. NBS-D. Radio Prop.*, vol. 66 D, no. 1, pp. 7-14.

Lee, S-W., G. Zarrillo and C. L. Law, September 1982, "Simple Formulas for Transmission Through Periodic Metal Grids or Plates," *IEEE Trans. Antenna and Propagation*, vol. AP-30, no. 5, pp. 904-909.

MacFarlane, G. G., December 1946, "Surface Impedance of an Infinite Parallel-Wire Grid at Oblique Angles of Incidence," *J. IEE*, Part IIIA, vol. 93, pp. 1523-1527.

BIBLIOGRAPHY (continued)

Marcuvitz, N., Editor, 1951, *Waveguide Handbook*, M.I.T. Rad. Lab. Ser. no. 10, McGraw-Hill, NY, pp. 280-289.

Otteni, G. A., November 1973, "Plane Wave Reflection from a Rectangular-Mesh Ground Screen," *IEEE Trans. Antenna and Propagation*, vol. AP-21, no. 6, pp. 843-851.

Rahmat-Samii, Y. and S-W. Lee, January 1985, "Vector Diffraction Analysis of Reflector Antennas with Mesh Surfaces," *IEEE Trans. Antenna and Propagation*, vol. AP-33, no. 1, pp. 76-90.

Scott, C., 1989, *The Spectral Domain Method in Electromagnetics*, Artech House, Norwood, MA.

Sivov, A. N., January 1961, "Incidence of a Plane Electromagnetic Wave on a Plane Grid (Case in Which the H-Vector is Parallel to the Wires)," *Radio Eng. Electron Phys.*, (USSR), vol. 6, no. 1, pp. 58-66.

Skwirzynski, J. K., and J. C. Thackray, 1959, "Transmission of Electromagnetic Waves Through Wire Gratings (Theory)," *Marconi Review*, 2nd Quarter, vol. 22, pp. 77-90.

Wait, J. R., September 1962, "Effective Impedance of a Wire Grid Parallel to the Earth's Surface," *IRE Trans. Antenna and Propagation*", vol. AP-10, no. 5, pp. 538-542.

Wait, J. R., April 1957, "The Impedance of a Wire Grid Parallel to a Dielectric Interface," *IRE Trans. Microwave Theory and Techniques*, vol. MTT-5, pp. 99-102.

Wait, J. R., September 1954, "Reflection from a Wire Grid Parallel to a Conducting Plane," *Can. J. Phys.*, vol. 32, pp. 571-579.